

Evaluation of Heavy Metal Pollution in the Suame Industrial Area, Kumasi, Ghana

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Introduction

Most cities in Ghana are densely populated, and lack of regulation, poor planning and zoning of activities, coupled with lack of resources to enforce by-laws, have led to localities with mixed activity; industrial, residential and commercial. Exacerbating this situation, there is little or no data on such industrial activities, and in cases where data exists, it appears to have no bearing on town planning policy. Mixed activity locations cater to light to heavy industries, including, for example, metal fabrication, car paint spraying, and car battery repair. The following localities are typical mixed activity and congested locations: Suame industrial area in Kumasi, Abossey Okai in Accra and the Tema industrial area. These unregulated activities lead to pollution of the environment and in particular, land and air pollution.

Background. Heavy metal pollution in industrial and residential areas in cities has become a public health issue in Ghana. Anecdotal evidence suggests that most industrial areas have elevated levels of heavy metals in soil. As a result of poor zoning and unregulated activities, large sections of seemingly industrial areas are also used as residential areas. There have been no studies on the levels of heavy metal contamination in such mixed activity locations.

Objectives. The study was undertaken to identify possible heavy metals and their concentrations in soil samples collected from the Suame Industrial Area, Kumasi, Ghana.

Methods. Soil samples were collected, processed and the concentration of copper (Cu), lead (Pb), zinc (Zn), cobalt (Co) and chromium (Cr) were analyzed using X-ray fluorescence (XRF).

Results. The concentration of all metals exceeded the threshold limit values (TLV). They also exceeded the European Soil Bureau Network (ESBN) maximum allowable limits (MAL), and are therefore considered to be pollutants. The results, expressed as mean concentration±standard deviation mg/kg (percent above TLV) were Pb: 414.83±159.38 mg/kg (418.9%), Cr: 264.84±189.15 mg/kg (353.1%), Co: 68.15±34.12 mg/kg (227.2%), Cu: 265.82±80.53 mg/kg (354.4%) and Zn: 3,215.84±4,074.54 mg/kg (1,607.9%). Furthermore, the concentrations of Pb and Co exceeded the United States Environmental Protection Agency (USEPA) residential soil regional screening levels (RSLs).

Conclusions. The elevated metal concentrations found in the present study demonstrate that the site is heavily polluted with Pb, Co and Cr. This is attributed to unregulated activities at the site; therefore, measures should be put in place to ameliorate the effects of potential heavy metal toxicity to workers, local residents and the environment. Re-zoning of activities and clear demarcation of residential and industrial areas is advocated.

Competing Interests. The authors declare no competing financial interests.

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Heavy metal pollution of soil samples from some of these localities is of great concern because of the dangers posed to workers, inhabitants and the environment. The high levels of metals recorded at these areas are alarmingly high. Therefore, the inhabitants, including children and the numerous workers who reside and work in these polluted environments, are at serious risk of heavy metals toxicity and greater awareness of this issue is needed.¹

It has been estimated that 20% of the total burden of disease in the developing world is due to

environmental pollution.² Therefore, raising awareness and increasing efforts to reduce the risk of pollution, including heavy metal pollution, would further decrease the burden of disease, and as a consequence, improve the well-being of the population and hence increase productivity. Heavy metals are almost everywhere in the environment, as a result of both anthropogenic and natural activities, and humans are exposed to them through various pathways.^{3,4}

Heavy metal accumulation in soils and plants is of increasing concern due to the potential human health risks as

this accumulation leads to food chain contamination.⁵ It is believed that the concentrations of these metals released into the ecosystem may lead to geo-accumulation, bio-accumulation, and bio-magnification.⁶ There have been many studies of soil pollution using different techniques, including magnetic susceptibility measurement, atomic absorption spectrophotometry, and neutron activation analysis.⁷⁻¹⁰

In this report, we quantitatively assessed the levels of copper (Cu), lead (Pb), zinc (Zn), cobalt (Co) and chromium (Cr) contamination in an area which functions both as an industrial and residential area in Suame, Kumasi, Ghana. This report is also intended to raise awareness of the issue of heavy metal contamination and to encourage regulation and creation of control measures by the country's Environmental Protection Agency. These measures could be in the form of zoning and clear demarcation or re-designation of activities, and construction of enclosures around the study area. Further, the separate collection and disposal of waste from industrial and domestic sources is strongly advocated.

Methods

Study Site

The Suame Industrial Area is an integral part of Kumasi in the Ashanti Region, Ghana. It is popularly known as "Magazine". The soil type in the area is mainly sandy soil. It lies at latitude 06°43'21.26" N and longitude -1°38'40.19" W. The area sees many forms of industrial use, such as car body part repair, auto mechanic shops, metal fabrication workshops (smelting, molding, welding), manufacturing of corn (cereal grains), mill parts and whole machines, and manufacture of aluminum and silver utensils. Also present are blacksmiths,

Abbreviations			
Ba	Barium	Mo	Molybdenum
Co	Cobalt	Ni	Nickel
Cr	Chromium	Pb	Lead
CrVI	Hexavalent chromium	RSL	Regional screening levels
Cu	Copper	Sr	Strontium
CV	Coefficient of variation	TLV	Threshold limit value
ESBN	European Soil Bureau Network	USEPA	United States Environmental Protection Agency
Fe	Iron	XRF	X-ray fluorescence
MAL	Maximum allowable limit	Zn	Zinc
Mn	Manganese		

carpenters, and car paint sprayers. Suame is also known for vigorous commercial activities including trading in all kinds of automobile spare parts, building materials and electrical appliances. Food and drinking bars are also located within the area. In addition, Suame also serves as a settlement area to some inhabitants of Kumasi and is densely populated.

A cursory look suggests that the soils are heavily polluted; there is very little vegetation, and the soil appears barren (Figure 1a, b), dark brown to black in some places, and there are patches where industrial wastes such as grease, automobile engine oil, tires and pieces of rusty metal have been discarded. In other areas, domestic refuse can be seen strewn about.

Sample Collection

Soil samples were taken from the

surface of the soil at 0–10 cm depth with the aid of a core sampler. In all, 20 samples were collected; 12 samples (three replicates from each sampling spot) were collected along a specified transect at intervals of 5 m, covering a total distance of 60 m. The transect was chosen alongside one of the longest walkways at the study site (Figure 1c). The remaining eight samples were taken at a random distance from the transect. However, as there were no clearly demarcated zones for residential, commercial or industrial activity, these samples were not treated separately. For instance, some artisans live in the same premises used as work places. In other areas, food is prepared, sold and eaten in the open, under trees next to a 'workshop' (Figure 1d). Children could also be seen playing in some work areas (Figure 1e). Therefore, the soil samples were treated as a composite rather than separately. The



1a



1b



1c



1d



1e

(Figure 1a, Top Left) shows the bare eroded soil surface of the study area (Figure 1b, Top Right) shows industrial activity in the study area with various artisans and a residential home in the background. (Figure 1c, Middle Left) shows the transect along which the samples were collected. In other areas, food is sold and eaten in the open, under trees next to a 'metal workshop' (Figure 1d, Middle Right). Children can also be seen playing in the foreground (Figure 1e, Bottom).

samples were bagged and labelled for easy identification.

Sample Processing

Samples were later air-dried for one

week and bagged. The bagged samples were then sent to the Geological Survey Department, Accra where the elemental analysis was performed. The samples were ground into

powered form using a sieve shaker (Fritsch sieve, Fritsch GmbH, Idar-Oberstein, Germany). The sieve shaker is a four-chamber sieve machine with decreasing pore sizes

	TLV	Mean	Range	Standard Deviation	CV	Above TLV
<i>Element</i>	mg/kg	mg/kg	mg/kg	mg/kg	%	%
Pb	100	418.9	(173.3–553.9)	159.4	38.4	418.9
Cr	75	264.8	(116.2–629.1)	189.2	71.4	353.1
Co	30	68.2	(37.8–117.6)	34.1	50.1	227.2
Cu	75	265.8	(117.9–410.5)	80.5	30.3	354.4
Zn	200	3,215.8	(551.3–13,260)	4,074.5	126.7	1,607.9

Table 1 — Mean Metal Concentrations, Standard Deviation and Coefficients of Variation Compared with Threshold Limit Values
 TLVs are based on airborne exposure, but were used as a toxicity index to supplement the USEPA guidelines for soil contamination

which works within a time frame. This can be easily reset depending on the quantity and level of smoothness required. Only samples with sizes smaller than the sieve (125 µm) were extracted into the lower chamber, resulting in fine samples. The milled samples were bagged and labeled and readied for elemental analysis.

Four grams of the milled soil samples were measured into a sample cup with an inner diameter of 28 mm with the aid of a chemical balance, and then homogenized with 0.9 g of Hoechst wax C (Merck Millipore, Darmstadt, Germany). Two small pebbles were added to help with thorough mixing and further grinding of the sieved sample with the wax. The sample container was then covered and placed in a mill machine (Mill MM 200, Retsch GmbH, Haan, Germany), where the mixture was sufficiently mixed into a very uniform state. The period for the milling process was set to approximately three minutes. Subsequently, the pebbles were removed from the sample container using a spatula. The resulting sample was poured into a die and covered. The die was then placed in a press machine and pelleted under a weight of 5 tons. The pellets were

removed and transferred to an X-ray fluorescence spectrometer (Spectro X-lab 2000, SPECTRO, Kleve, Germany) for the analysis.

Sample Analysis

Following optimization of the X-ray fluorescence (XRF) spectrometer parameters via a connected desktop computer, the pelleted samples were loaded onto the instrument. Heavy metal analysis was performed over a period of 12 hours. The results were displayed on a monitor and organized in Microsoft Excel 2007 (Microsoft, Redmond, WA, USA).

The results of the metal concentrations of three replicates from each sampling spot are expressed as mean ± standard deviation (and range) in mg/kg, coefficient of variation (CV)%, and were compared with their threshold limit values (TLV). The concentrations were also compared with the United States Environmental Protection Agency (USEPA) limits maximum heavy metal soil regional screening levels (RSLs) for both residential and industrial land use, and the European Soil Bureau Network (ESBN) maximum allowable limits (MAL).^{11,12}

Results

The results showed that the concentrations of the heavy metals Cu, Pb, Zn, Co and Cr were all very high in the soil (Table 1). Graphs of concentration (mg/kg) against separation distance (m) were plotted as shown in Figures 2–6. The mean concentrations were Pb: 418.8 mg/kg (range 175 to 730 mg/kg; CV 159.4%), Cr: 264.84 mg/kg (range 116 to 629 mg/kg; CV 189.1%), Cu: 265.82 mg/kg (range 118 to 411 mg/kg; CV 80.53 %), Co: 68.15 mg/kg (range 38 to 118 mg/kg; CV 34.12%) and Zn: 3,215.81 mg/kg (range 551.3 to 13,260 mg/kg; CV% 4,072.5%). The mean concentrations exceeded their TLV as follows: Pb 418.9%, Cr 353.1%, Cu 354.4%, Co 227.2% and Zn 1,607.9%.

The concentration of iron (Fe), manganese (Mn), barium (Ba), strontium (Sr), nickel (Ni) and molybdenum (Mo) were much lower than their TLV and the USEPA RSLs for industrial land use, and therefore, they were considered to be non-pollutants, and as such no further discussion is provided.

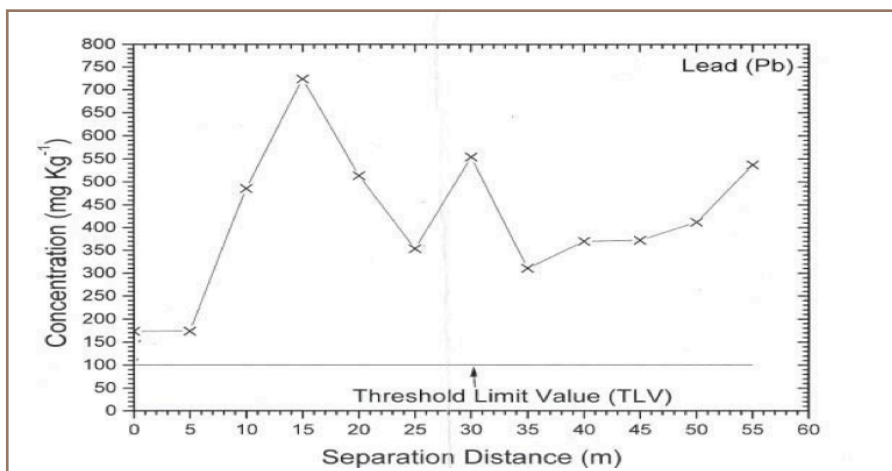


Figure 2 — Concentration (mg/kg) plotted against separation distance (m) for lead

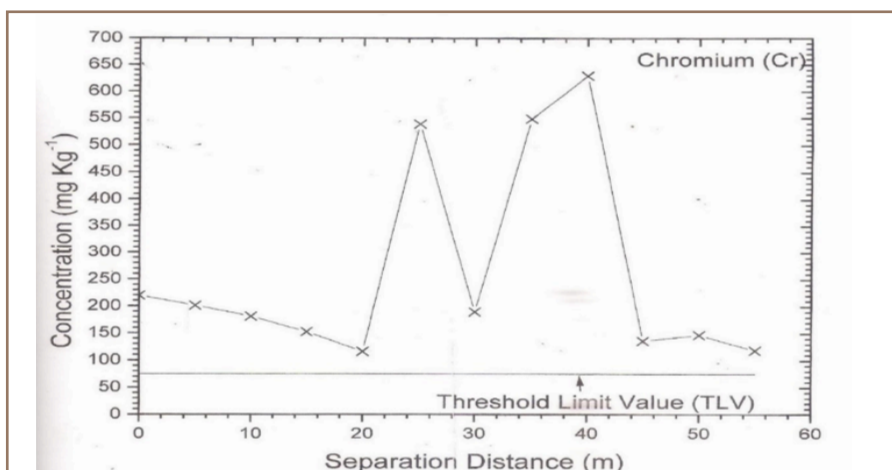


Figure 3 — Concentration (mg/kg) plotted against separation distance (m) for chromium

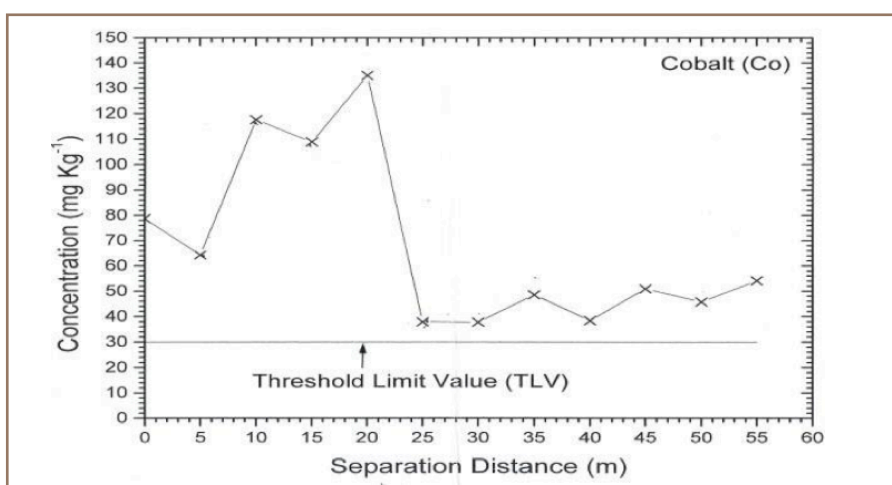


Figure 4 — Concentration (mg/kg) plotted against separation distance (m) for cobalt

Discussion

The average concentrations of some of the heavy metals detected in a control soil (control i.e. natural soil left untreated and uncultivated) at the Central Agricultural Research Station at Kwadaso, Kumasi were Pb: 0.095 mg/kg, Cu: 0.0112 mg/kg and Zn: 0.015 mg/kg.¹³ This indicates that the metal concentrations at the study site far exceeded those of the control by several orders of magnitude, even though the sites are just 5.3 km apart.

As shown in Figure 2, initially the 175 mg/kg concentration of Pb was constant up to 5 m and then increased to a maximum of 730 mg/kg at a distance of 15 m. It then dropped steadily to about 370 mg/kg at 25 m, increased slightly to about 570 mg/kg at 30 m, until dropping just below a concentration of about 370 mg/kg and finally rising from a distance of 35 m to 55 m at a concentration of about 490 mg/kg. The reason for the variations in the concentration of Pb has to do with the landscape. The activities in this area involve spraying of cars, trucks, gates and other fabrication works, and these paint pigments contain Pb. In addition, lead acid storage batteries were displayed in this area.

The concentration of Cr was 264.84 mg/kg (range 125 mg/kg to 640 mg/kg), and this was relatively high compared with the TLV of 75 mg/kg (Figure 3). The concentration of 220 mg/kg for Cr dropped to about 120 mg/kg at a distance of 20 m. It increased sharply to about 540 mg/kg at 25 m and then dropped to 200 mg/kg at 30 m. The maximum concentration was 640 mg/kg, and dropped to about 135 mg/kg at 55 m.

The Co concentration level varied from 38 mg/kg to 136 mg/kg, falling outside the normal threshold value of 30 mg/kg. As shown in Figure 4, the

concentration of Co dropped initially from 79 mg/kg to 65 mg/kg at 5 m, increased to a maximum of 136 mg/kg, then dropping to 38 mg/kg, which was constant up to a distance of 30 m. It decreased to 56 mg/kg at 55 m. The least polluting metal based on the percentage above the TLV was Co, 227.3% at a distance of 25 m. The concentration of Co was the lowest of all the metals studied, indicating minimal use of Co in this area.

The concentration of Cu in soil in the study area ranged from 120 to 410 mg/kg, exceeding the threshold concentration value of 75 mg/kg for Cu. As shown in Figure 5, the initial concentration of Cu was 200 mg/kg. It then rose to 320 mg/kg up to a distance of 15 m and then to a minimum concentration of about 120 mg/kg at 20 m. There was a sharp rise in concentration to 410 mg/kg at 25 m. From this point there was no consistency in the concentrations up to about 23 mg/kg at 45 m, then increasing gradually to a concentration of 290 mg/kg at 55 m.

The concentration of Zn was slightly above the threshold limit value of 200 mg/kg as shown in Figure 6. The initial concentration of Zn was about 6,200 mg/kg, then dropping to 600 mg/kg at a distance of 5 m. There was also an increase in concentration of about 7,800 mg/kg at 10 m and then dropping to 5,000 mg/kg. The maximum concentration was recorded as 13,400 mg/kg at a distance of 20 m. It then dropped slowly to 600 mg/kg. The most polluting metal based on the percentage above the TLV was Zn, 1607.9% at a distance of 25 m. Zn is used to galvanize iron and steel which is used for automobile bodies and in car battery repair. These activities in the area presumably resulted in the high concentrations of Zn.

The soil heavy metal concentrations

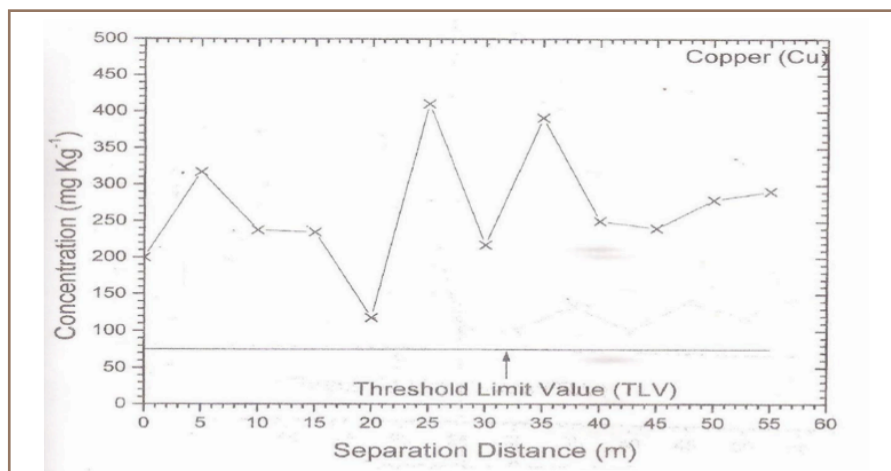


Figure 5 — Concentration (mg/kg) plotted against separation distance (m) for copper

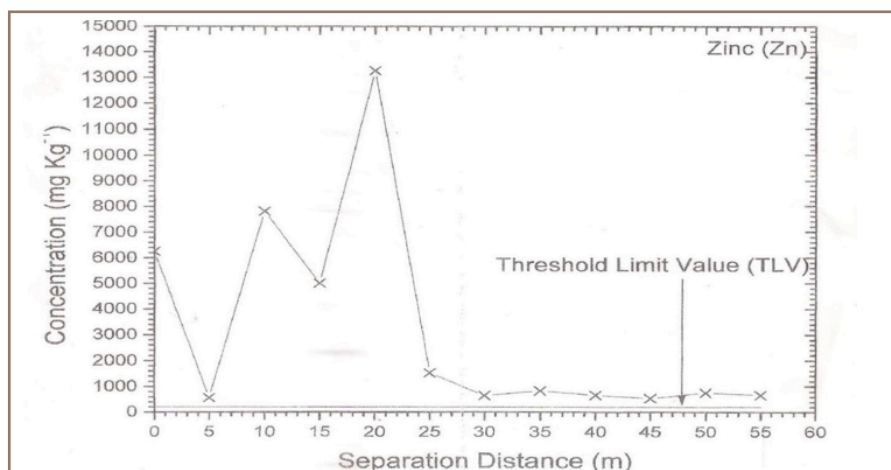


Figure 6 — Concentration (mg/kg) plotted against separation distance (m) for zinc

were compared with the RSLs for residential and industrial land use and the USEPA limits (Table 2). Two metals, Pb and Co, exceeded the residential limits by 4.7% and 196.5%, respectively, but they did not exceed the industrial limits. There is an RSL value for (hexavalent chromium (CrVI) = 0.3 mg/kg), but not for total chromium. However, CrVI was not measured in soil in this study. Chromium is used to harden steel, and in the manufacture of steel for utensils, roofing sheets, car frames, window frames etc., to prevent rusting.

In addition, chromium plating is used to give a polished finish to many steel products such as car and truck parts and furniture. In contrast, the mean concentration of Cu and Zn were below both the USEPA residential and industrial soil RSLs. The mean concentrations of all the heavy metals also exceeded the ESNB MAL. The percentage concentrations above the MAL of the heavy metals were: Pb 318.9%, Cr 164.8%, Co 36.4%, Cu 165.4% and Zn 972.2% (Table 2).

The results of the present analysis

	USEPA Soil Metal Concentrations					ESB MAL	
	Mean	Resident Soil		Industrial Soil		Soil	
Element	mg/kg	mg/kg	% Above Max	mg/kg	% Above Max	mg/kg	% Above Max
Pb	418.9	400	4.7	800	DNE	100	318.9
Cr VI	ND	.3	—	6.3	—	—	—
CrT	264.8	ND	ND	ND	ND	100	164.8
Co	68.2	23	196.5	350	DNE	50	36.4
Cu	265.8	3,100	DNE	47,000	DNE	100	165.8
Zn	3,215.8	23,000	DNE	35,000	DNE	300	972.0

Table 2 — Mean concentration, compared with their European Soil Bureau maximum allowable limit for soil and US EPA maximum soil limits for residential and industrial land use

Abbreviations: DNE, does not exceed maximum limits; ND, not detected; NE, not established; CrT, Chromium total; ESB MAL, European Soil Bureau maximum allowable limit for soil

are a cause for concern because of the excessively high metal concentrations compared with their TLVs. Each analyzed heavy metal had a concentration above its threshold limit value, indicating the presence of pollution in the study area. This is directly attributable to the activities conducted in this area. For instance, Zn, Pb, and Cu are released into the environment due to improper disposal of car batteries and leakage of diesel and engine oil from vehicles. Similarly, paint spraying of car parts, metal fabrication, and the burning of waste materials like car tires, plastics, etc. also release metal pollutants into the atmosphere which are then deposited. These heavy metals have adverse effects on the human population in the area, other living organisms and the environment.

Conclusion

From the results of the present study, it is evident that heavy metals are present in considerably high concentrations in the soil in the Suame industrial area. The levels of Cu, Pb, Zn, Co,

and Cr have exceeded their threshold limit values. Of these metals, Pb had a coefficient of variation of 38.4%, Cu had the smallest coefficient of variation at 30.3%, while Zn had the highest coefficient of variation at 126.7%. The percentage concentrations above the TLVs of the heavy metals were: Pb 418.9%, Cr 353.1%, Cu 354.4%, Co 227.2% and Zn 1,607.9%. A comparison of concentrations with the USEPA soil RSLs indicate that the most polluting metals were Pb and Co, in increasing order. Compared with ESN limits, all the metals can be considered to be highly polluting, in the increasing order of Co, Cu ≈ total Cr, Pb and Zn. This indicates that mixed activity use in Suame, Kumasi poses a potential health threat to the inhabitants and workers in this industrial area. Industrial activities have been traced to the many chemicals used for production and repair of metallic parts and components, and to other anthropogenic activities such as refuse accumulated in many parts of the Suame industrial area. Remediation

should be carried out so as to render the polluted soil and groundwater safe. Industrial activities should also be monitored to include safe collection and disposal of industrial and domestic wastes.

We aim to raise awareness of heavy metal contamination and to encourage creation of effective regulation and control measures including zoning and clear demarcation, regulation of industrial activities and erection of enclosures around work areas. In addition, safe and separate collection and disposal of waste from both industrial and domestic sources is advocated.

References

1. Kodom K, Preko K, Boamah D. X-ray fluorescence (XRF) analysis of soil heavy metal pollution from an industrial area in Kumasi, Ghana. *Soil Sediment Contam Int J* [Internet].

2012 Oct [cited 2014 May 20];21(8):1006- 21.

Available from: https://www.researchgate.net/publication/254218891_X-Ray_Fluorescence_XRF_Analysis_of_Soil_Heavy_Metal_Pollution_from_an_Industrial_Area_in_Kumasi_Ghana

2. Kampalath RN, Jay JA. Sources of mercury exposure to children in low – and middle – income countries. *J Health Pollut* [Internet]. 2015 Jun [cited 2016 Apr 12];5(8):33-51. Available from: <http://www.journalhealthpollution.org/doi/full/10.5696/j2156-9614-5-8.33>

3. Khan S, Cao Q, Zheng YM, Huang YZ, Zhu YG. Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. *Environ Pollut* [Internet]. 2008 Apr [cited 2013 Jul 12];152(3):686-92. Available from: <http://www.sciencedirect.com/science/article/pii/S0269749107003351> Subscription required to view

4. Wilson B, Pyatt FB. Heavy metal dispersion, persistence, and bioaccumulation around an ancient copper mine situated in Anglesey, UK. *Ecotoxicol Environ Saf* [Internet]. 2007 Feb [cited 2016 Apr 12];66(2):224-31. Available from: <http://www.sciencedirect.com/science/article/pii/S0147651306000546> Subscription required to view.

5. Singh A, Sharma RK, Agrawal M, Marshall FM. Risk assessment of heavy metal toxicity through contaminated vegetables from waste water irrigated area of Varanasi, India. *Trop Ecol* [Internet]. 2010 [cited 2016 Apr 12];51(2S):375-87. Available from: <http://environmentportal.in/files/Risk%20assessment%20of%20heavy%20metal%20toxicity.pdf>

6. Lokeshwari H, Chandrappa GT. Impact of heavy metal contamination of Bellandur Lake on soil and cultivated vegetation. *Curr Sci* [Internet]. 2006 Sep 10 [cited 2016 Apr 12];91(5):622-7. Available from: <http://www.iisc.ernet.in/currsci/sep102006/622.pdf>

7. Gautam P, Blaha U, Appel E. Integration of magnetism and heavy metal chemistry of soils to quantify the environmental pollution in Kathmandu, Nepal. *Isl Arc* [Internet]. 2005 Dec [cited 2016 Apr 12];14(4):424-35. Available from: <http://onlinelibrary.wiley.com/doi/10.1111/j.1440-1738.2005.00496.x/abstract> Subscription required to view.

8. Ikenaka Y, Nakayama SMM, Muzandu K, Choongo K, Teraoka H, Mizuno N, Ishizuka M. Heavy metal contamination of soil and sediment in Zambia. *Afr J Environ Sci Technol* [Internet]. 2010 Nov [cited 2016 Apr 12];4(11):729-39. Available from: <http://www.ajol.info/index.php/ajest/article/view/71339/60292>

9. Olayiwola OA. An assessment of soil heavy metal pollution by various allied artisans in auto-mechanic workshop in Osun State, Nigeria. *Electron J Environ Agric Food Chem*. 2011;10(2):1881-6.

10. Waheed S, Siddique N, Hamid Q, Chaudhry MM. Assessing soil pollution from a municipal waste dump in Islamabad, Pakistan: a study by INAA and AAS. *J Radioanal Nucl Chem* [Internet]. 2010 Sep [cited 2016 Apr 12];285(3):723-32. Available from: <http://link.springer.com/article/10.1007%2Fs10967-010-0623-4> Subscription required to view.

11. US Environmental Protection Agency risk-based Regional screening levels (RSLs) - generic tables (November 2015) [Internet]. Washington DC: United States Environmental Protection Agency; [updated 2016 Mar 7; cited 2016 Apr 12]. Available from: <https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables-november-2015>

12. Lacatusu R. Appraising levels of soil contamination and pollution with heavy metals. In: Heineke HJ, Eckelmann W, Thomasson AJ, Jones RJ, Montanarella L, Buckley B, editors. Land information systems: developments for planning the sustainable use of land resources. [Internet]. Brussels, Belgium: European Soil Bureau; 1998. Section 5, Environmental applications; [cited 2016 Apr 12]; p. 393-402. ESNB research report no.: 4. Available from: http://eusoils.jrc.ec.europa.eu/ESDB_Archive/eusoils_docs/esb_rr/n04_land_information_systems/contents.html

13. Sadick A, Amfo-Otu R, Acquah SJ, Nketia KA, Asamoah E, Adjei EO. Assessment of heavy metal contamination in soils around auto mechanic workshop clusters in central agricultural station, Kumasi, Ghana. *Appl Res J* [Internet]. 2015 [cited 2016 Apr 12];1(2):12-9. Available from: <http://www.arj.presbyuniversity.edu.gh/index.php/ARJ/article/view/17/7>